MULTISPECTRAL SOLUTIONS, INC.

Response to FCC Notice of Inquiry
ET Docket No. 98-153
"Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems."

Submitted to
Federal Communications Commission, Washington, DC

By
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1 March 2000

1. Introduction

Multispectral Solutions, Inc. (MSSI) is pleased to submit this second response to the Federal Communications Commission (FCC) Notice of Inquiry, ET Docket No. 98-153, pertaining to "Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems."

Our response is directed at UWB communications and short range radar applications (other than Ground Penetrating Radar and through-the-wall stud finders which may also utilize UWB technology).

2. Specific Recommendations

As discussed in more detail below, MSSI specifically recommends that the FCC:

1. Prohibit the use of UWB communications systems below 2 GHz; and,

2. Allow certain classes of UWB communications systems above 2 GHz subject to a peak power constraint.

2.1 Recommendation – Prohibit UWB communications systems below 2 GHz

In a very recent *ex parte* notification[1], Time Domain Corporation stated that "many Part 15 certified devices interfere with GPS at very short ranges," and that "UWB devices exhibit the same characteristics as other Part 15 certified devices." They also demonstrated significant GPS interference from UWB in 2 out of 12 test modes. In this notification, "harmful interference (was) assumed to have occurred when four or fewer satellites (were) tracked." Unfortunately, with the loss of *any* satellite, GPS accuracy is degraded.

In a presentation[2] given at the 1999 UWB Conference for Radio and Radar Technology, Stanford University and Interval Research illustrated the deleterious effects of certain types of ultra wideband emitters on the ability of a wide variety of GPS receivers to maintain lock. (Satellite acquisition, which is even more susceptible to in-band interference, was not even discussed.) Figure 1 below is excerpted from this presentation. In the same presentation, the authors recommended that, to achieve more protection for GPS, the UWB system designer should "place UWB spectrum far from GPS."

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[1] *Ex Parte* Notification, 17 February 2000, David E. Hilliard, Counsel for Time Domain Corporation.

[2] Enge, P., K. Gromov and J. Jung (Stanford University), G.R. Aiello and G. Rogerson (Interval Research Corporation), "A Cooperative Program to Assess Interference from Ultra Wide Band Technologies to the Global Positioning System", *1999 UWB Conference for Radio and Radar Technology*, Washington, DC, 29 September 1999.

Interference Range (meters)

	Narrow Correlator	Inexpensive Hand-Held	Experimental	Survey Grade
Bursty 40%	3-10	3-10	30-100	30-100
Bursty 50%	3-10	30-100	5-15	30-100
Bursty 70%	3-10	30-100	5-15	30-100
Bursty 100%	3-30	30-100	3-100	30-100
PRF	1-3	5-15	30-100	1-3
Dither	3-10	30-100	30-100	30-100
Random	3-10	30-100	30-100	30-100

- Range uncertainty reflects
  - E-field measurement errors
  - Difficult to identify point of degradation
- Based on limited number of UWB signal designs
- Need more exhaustive measurements
- No safety margin

Source: Per Enge et al., "A Cooperative Program to Assess Interference from Ultra Wide Band Technologies to the Global Positioning System," ***1999 UWB Conference,*** **Washington, DC, 29 Sept. 1999**

Figure 1. Interference Matrix from Stanford/Interval Presentation.

On December 9, 1999 at Stanford University, Professor Per Enge (an internationally recognized expert on GPS) demonstrated a very low power UWB source, provided to Stanford by Interval Research, which caused a GPS receiver to lose lock on every satellite within its field of view. Stanford's research was funded by the U.S. Department of Transportation.

It can therefore be concluded that low power UWB operation which falls within GPS assigned frequencies (L1 centered at1575.42 MHz, L2 centered at 1227.60 MHz and the new L5 centered at 1176.45 MHz, the latter a Safety of Life Navigation Signal), may cause serious interference to GPS. Aside from navigation, GPS is also used in emerging Internet applications for precision timing and position location, and would similarly be adversely affected.

However, the consensus of the UWB industry appears to be that filtering to stay outside of GPS frequencies would *not* affect the performance of ultra wideband systems used for communications applications. This view is supported by Multispectral Solutions, Inc., Lawrence Livermore National Laboratories[3], TEM Innovations[4], XtremeSpectrum[5], Fantasma Networks[6] and Time Domain Corporation[7,8].

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[3] Technical discussions with Rex Morey, Lawrence Livermore National Laboratory.

[4] "A large proliferation of UWB devices below 5.6 GHz should not be permitted due to GPS and FAA radar vulnerability to interference," TEM Innovations response to NOI ET 98-153.

[5] Martin Rofheart, XtremeSpectrum, statement at Air Transport Association (ATA) Meeting, 9 February 2000.

[6] James Lovette, Fantasma Networks, Inc., statement at FCC Open Forum, 16 February 2000.

[7] Time Domain Corporation Patent Cooperation Treaty (PCT) Filing PCT/US99/06218, 30 September 1999 Filed 23 March 1999.

For example, in Time Domain Corporation's recent PCT filing[7] it was stated that (**bold** emphasis added)

> "Impulse radio refers to a radio system based on a waveform that approaches the impulse response of the available bandwidth. In the widest bandwidth embodiment, the resulting waveform approaches one cycle per pulse at the center frequency. **In more narrow band embodiments, each pulse consists of a burst of cycles usually with some spectral shaping to control the bandwidth to meet desired properties such as out of band emissions** or in-band spectral flatness, or time domain peak power or burst off time attenuation."
>
> "Any practical implementation will deviate from the ideal mathematical model by some amount, which may be considerable since **impulse radio systems can tolerate seemingly considerable deviation with acceptable system consequences**. This is especially true in microwave implementations where precise waveform shaping is difficult to achieve."

In a recent U.S. Patent[8], Time Domain Corporation stated that

> "In the preferred embodiment, the emitted signal(s) are wideband or ultrawide-band signals. However, the **emitted signal(s) can be spectrally modified by filtering of the monocycle pulses**. This bandpass filtering will cause each monocycle pulse to have more zero crossings in the time domain. **In this case, the impulse radio receiver must use a similar waveform in the cross correlator to be efficient."**

Examples of MSSI ultra wideband equipment using spectrally filtered waveforms are illustrated in Figure 2 below.

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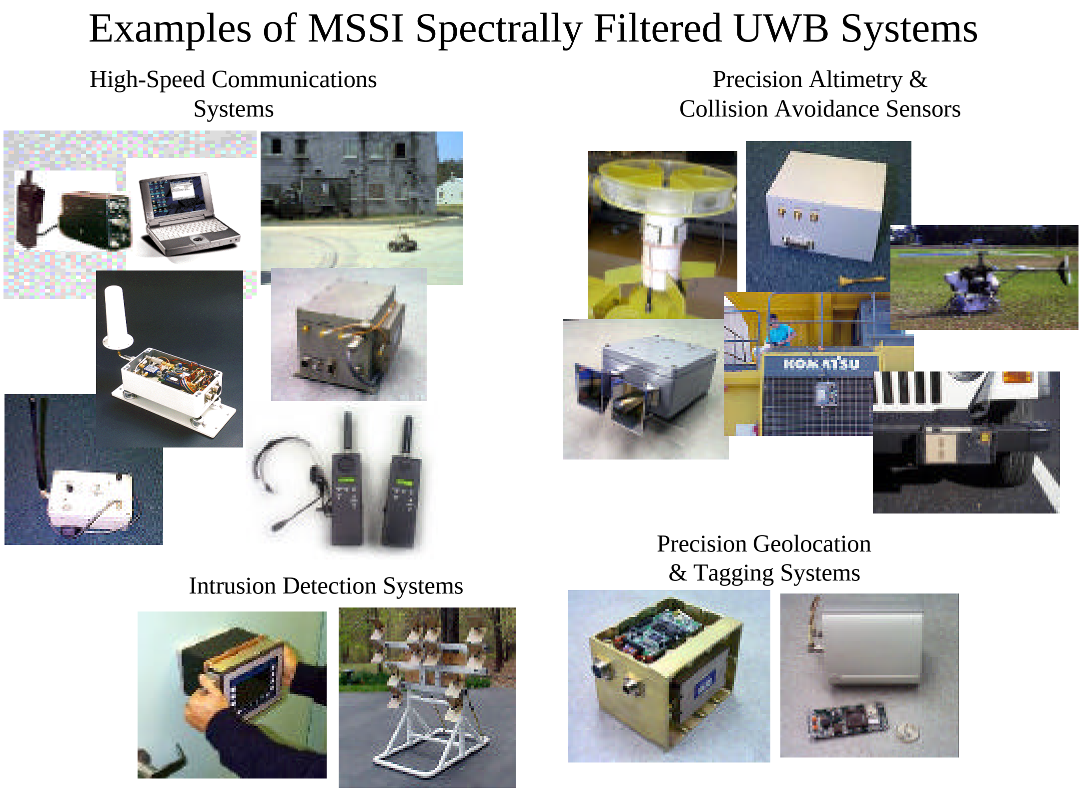
[8] Time Domain Corporation U.S. Patent 5,995,534 "Ultrawide-band Communications System and Method", 30 November 1999, Filed 10 October 1997.



Spectrally Filtered UWB Systems Can Address All Known Customer Requirements

Figure 2. Examples of MSSI Spectrally Filter UWB Systems.

As correctly pointed out by Ms. Sally Frodge (U.S. Department of Transportation) at the Air Transport Association meeting to discuss Ultra Wideband on 9 February 2000, GPS is *not* the only issue with respect to interference. There are also an extremely large number of commercial, industrial and military users within the frequency bands below 2 GHz.

A list of just the restricted bands alone (cf. Sec. 15.205) illustrates the FCC concerns for emissions below 2 GHz (cf. Table below). As seen, the maximum available bandwidth below 2.0 GHz is 346 MHz (614 - 960 MHz); however, TV channels 38 through 83, cellular telephone and other users occupy this spectrum.

Table 1. §15.205 Restricted bands of operation

MHz	MHz	MHz	GHz
0.090–0.110	16.42–16.423	399.9–410	4.5–5.15
[1] 0.495–0.505	16.69475–16.69525	608–614	5.35–5.46
2.1735–2.1905	16.80425–16.80475	960–1240	7.25–7.75
4.125–4.128	25.5–25.67	1300–1427	8.025–8.5
4.17725–4.17775	37.5–38.25	1435–1626.5	9.0–9.2
4.20725–4.20775	73–74.6	1645.5–1646.5	9.3–9.5
6.215–6.218	74.8–75.2	1660–1710	10.6–12.7
6.26775–6.26825	108–121.94	1718.8–1722.2	13.25–13.4
6.31175–6.31225	123–138	2200–2300	14.47–14.5
8.291–8.294	149.9–150.05	2310–2390	15.35–16.2
8.362–8.366	156.52475–156.52525	2483.5–2500	17.7–21.4
8.37625–8.38675	156.7–156.9	2655–2900	22.01–23.12
8.41425–8.41475	162.0125–167.17	3260–3267	23.6–24.0
12.29–12.293	167.72–173.2	3332–3339	31.2–31.8
12.51975–12.52025	240–285	3345.8–3358	36.43–36.5
12.57675–12.57725	322–335.4	3600–4400	([2])
13.36–13.41			

[1] Until February 1, 1999, this restricted band shall be 0.490–0.510 MHz.
[2] Above 38.6

Below 2 GHz, the spectrum is extremely congested. In fact, even above 2 GHz, there are few spectral regions where UWB systems may operate without impinging upon a currently restricted band.

One of these frequency ranges, namely 5.46 to 7.25 GHz (with 2.29 GHz of available bandwidth), may be ideal for initial development of UWB systems for in-building and vehicle-to-roadside communications and short range radar applications. As a consequence, the FCC may wish to initially consider restriction of Part 15 UWB communications devices to frequencies within this band, and perhaps provide additional incentives to operate there by allowing higher peak power levels for high-speed, line-of-sight (e.g., Internet last mile) applications. This would accelerate the development of high-speed, digital domain, products and services as was contemplated for development in the U-NII bands from 5.15-5.35 and 5.725-5.825 GHz.

In summary, since:

> Certain UWB emitters, which have been proposed for use under modified Part 15 regulations, have been demonstrated to cause significant interference to GPS (interference to other spectrum users has yet to be assessed);
>
> The UWB industry consensus is that filtering can be accomplished with acceptable system consequences; and,
>
> The maximum available bandwidth without impinging on a restricted band is only 346 MHz below 2 GHz;

it is evident that unlicensed UWB operations should be restricted to frequency bands above 2 GHz.

Furthermore, since 5.46 to 7.25 GHz (2.29 GHz of instantaneous bandwidth) is available *outside* of the restricted bands of operation, MSSI recommends that the FCC also consider further restricting unlicensed Part 15 UWB use to this band (until further independent testing by NTIA can be accomplished below 5.46 GHz), and consider relaxing peak power constraints for UWB emissions within this segment.

2.2 Recommendation – Allow UWB communications systems above 2 GHz subject to appropriate peak power constraints

2.2.1 An Appropriate Definition for UWB

From its early origins in the late 1950's (cf. http://www.multispectral.com/history.html), ultra wideband (originally referred to as impulse, carrier-free, and baseband) waveforms had been characterized as waveforms whose spectral envelope was determined by the magnitude Fourier transform of an extremely short duration pulse. These pulses typically represented from one to several cycles of an "apparent" RF carrier frequency. The bandwidth of such waveforms was essentially independent of the modulation rate (for UWB communications) or the pulse repetition frequency (for radar).

In 1990, a DARPA panel on Ultra Wideband Radar defined a UWB radar as "..any radar whose fractional bandwidth is greater than 0.25 regardless of the center frequency or the signal time-bandwidth product."[9] Unfortunately, this definition has a fundamental flaw as is seen in the following figure.

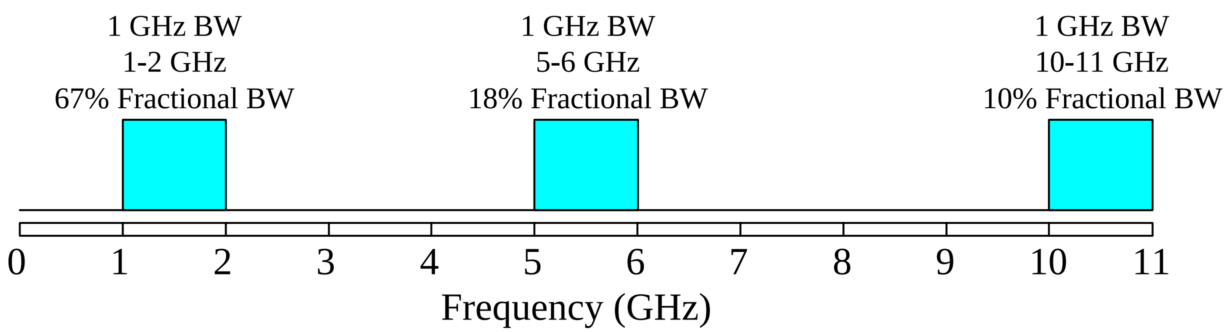


Figure 3. Fractional bandwidth changes with operational center frequency.

As illustrated in Figure 3, fractional bandwidth (the ratio of the instantaneous bandwidth to the operational center frequency) decreases with increasing center frequency for a waveform having a fixed instantaneous bandwidth.[10]

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[9] *Assessment of Ultra-Wideband (UWB) Technology*, Report R-6280, prepared by OSD/DARPA UWB Radar Review Panel, July 13, 1990.

[10] It is important to note that, until relatively recently (within last 10 years or so), it was not economically feasible to generate useful UWB energy at frequencies above 2 GHz. However, with the advent of new devices spawned by the rapidly expanding wireless industry, energy well into the millimeter wave region can now be readily produced.

For UWB communications, instantaneous bandwidth is independent of modulation rate. However, bandwidth affects multipath immunity, duty cycle (and, hence, average power), maximum data rate, etc. All of these properties are *independent* of center frequency. Frequency, of course, affects range (for a given antenna size) and can determine the type of propagation effects (e.g., ground wave, sky wave, etc.).

In general, UWB communications systems utilize *excess bandwidth* – i.e., bandwidth beyond that required by modern Shannon theory – to

> Reduce transmitted energy density for covert communications (low probability of detection) and low probability of interference;
>
> Resolve multipath signal returns for in-building, high-speed communications and precision geolocation functions; and,
>
> Take advantage of unique propagation modes utilizing inherent frequency diversity.

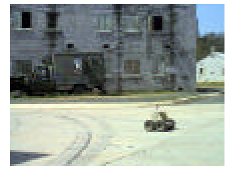
Thus, an appropriate communications-theoretic definition for a UWB waveform would be as follows:

> A communications system utilizes an ultra wideband emission if:
>
> > occupied BW is independent of modulation data rate;
> >
> > envelope of power spectral density is a function of the shape and duration of a single emitted pulse (spectral lines can appear at high data rates, but envelope stays fixed); and,
> >
> > Excess BW (EBW) ≡ (Occupied BW)/(Effective Data Rate) >> 1 (e.g., EBR > 10 dB).

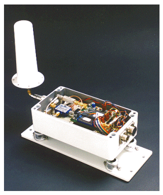
Examples of current MSSI military and government ultra wideband communications systems, together with their corresponding Excess Bandwidth (EBW) and Fractional Bandwidth (FBW), are illustrated in Figure 4 below. Note that, in several cases of practical importance, FBW does not satisfy the arbitrarily selected DARPA definition of FBW > 0.25.

WLAN
1.544 Mb/s
VHF/UHF
EBW = 18 dB
FBW = 22%

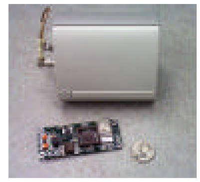
UAV Video Link
2.0-25.0 Mb/s
L-band
EBW = 23 dB
FBW = 27%



Video/C&C
256 kb/s
L-band
EBW = 32 dB
FBW = 27%



Point-to-Point
128 kb/s
L-band
EBW = 35 dB
FBW = 27%



Vehicle-to-Roadside Tag
115.2 kb/s
L-band
EBW = 34 dB
FBW = 17%

Point-to-Point
128 kb/s
L-band (S-band)
EBW = 35 (42) dB
FBW = 27 (15) %

Precision Location
1 kb/s (burst)
L-band
EBW = 56 dB
FBW = 27%

Point-to-Point
128 kb/s
low-VHF
EBW = 22 dB
FBW = 50%

EBW = Excess BW Ratio
FBW = Fractional BW

Figure 4. MSSI UWB Communications Systems.

For UWB radar, on the other hand, it is the *instantaneous* bandwidth (BW) which affects resolution properties, *independent* of operational carrier frequency. Thus, for example, a 1 GHz bandwidth radar at 1.5 GHz (67% fractional BW) has the same resolution as a 1 GHz bandwidth radar at 10.5 GHz (10% fractional BW). Of course, carrier frequency affects range (given antenna size and target radar cross section (RCS) properties) and penetration properties (e.g., for Ground Penetrating Radar).

Thus, UWB radar systems utilize short pulse durations – i.e., *wide instantaneous bandwidth* – to

Provide precise range resolution;

Provide precise range-gate cutoff (for clutter rejection and to define a region-of-interest);

Reduce transmitted energy density for covert applications (low probability of detection) and for low probability of interference to other systems;

Take advantage of wideband RCS properties for detection of extended and complex RCS targets;

Take advantage of unique material penetration properties such as for GPR, foliage penetration, etc.

It was noted by Taylor[11] that conventional radars typically have fractional bandwidths of less than 1%. (This is primarily the reason DARPA considered a large fractional bandwidth to discriminate UWB from conventional radars.) However, as noted above, fractional bandwidth decreases with increasing carrier frequency, but radar range resolution remains unaffected.

Thus, an appropriate radar-theoretic definition for a UWB waveform would be as follows:

> A radar system utilizes an ultra wideband emission if the radar pulsewidth is less than TBD ns.

The pulsewidth effectively sets the radar's instantaneous bandwidth. A suitable value for pulsewidth might be 10 ns or less.

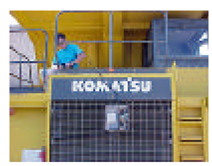
Examples of current MSSI military and government ultra wideband radar systems, together with their corresponding Excess Bandwidth (EBW) and Fractional Bandwidth (FBW), are illustrated in Figure 5 below. Note that, in several cases of practical importance, FBW does not satisfy the arbitrarily selected DARPA definition of FBW > 0.25; however, these are short pulse devices in which the pulsewidth is quite short (typically less than 2.5 ns). In fact, there are numerous applications for short pulse radars wherein the fractional bandwidth is appreciably less than 25% as seen in this Figure.

Aircraft/UAV
Altimeter/Collision Avoidance
C-band (5.4-5.9 GHz)
PW = 2.0 ns
FBW = 8.9%

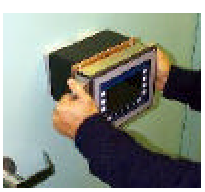
Automobile Collision Avoidance
C-band (5.4-5.9 GHz)
PW = 2.0 ns
FBW = 8.9%

Radar Fuze
X-band (9-11 GHz)
PW = 500 ps
FBW = 20%

Collision Avoidance
X-band (9-11 GHz)
PW = 500 ps
FBW = 20%



Collision Avoidance
C-band (5.4-5.9 GHz)
PW = 2.0 ns
FBW = 8.9%



Through-Wall Sensor
L-band
PW = 2.5 ns
FBW = 27%

Surveillance System
L-band
PW = 2.5 ns
FBW = 27%

PW = Pulsewidth
FBW = Fractional BW

Figure 5. MSSI UWB Communications Systems.

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[11] Taylor, J.D., *Introduction to Ultra-Wideband Radar Systems*, CRC Press, Boca Raton, FL, 1995, Chapter 1.

2.2.2 Appropriate Measurement Techniques for UWB Waveforms

There has been considerable discussion about the need for a pulse desensitization factor for UWB emission measurements. As will be shown below, peak pulse power together with instantaneous bandwidth uniquely determine the performance (e.g., range, bit error rate, probability of detection, probability of interference, etc.) of a short pulse system. Thus, a measurement of peak pulse power is an *essential* parameter for UWB waveform characterization; and MSSI recommends maintaining pulse desensitization factor measurements for UWB Part 15 type approval. Indeed, as discussed below, permissible levels of UWB emissions should be characterized by a peak power constraint, allowing for arbitrarily large peak-to-average ratios so as to reduce average emitted energy.

To further clarify these points, consider the following set of claims that have been made for the removal of pulse desensitization measurements (Time Domain Corporation, response to NOI ET98-153, dated 7 December 1998):

> **Claim 1:**
>
> "Since wideband and narrowband systems can only intercept a small fraction of the total energy of a UWB pulse, a measure of the radiated peak envelope power of a UWB signal would greatly overestimate the interference potential of the UWB emission."
>
> **Response to Claim 1:**
>
> Unfortunately, receivers can be affected by spurious emissions coming from other than through the antenna filter. For example, signal overload at intermediate frequencies, signal pickup at sensitive detector stages, etc. can occur when out of band emissions are present.
>
> Spectral lines produced by a high pulse repetition frequency (PRF) UWB emitter are, in fact, narrowband in nature. Thus, while the overall UWB spectrum may be spread over hundreds or thousands of MHz, the total pulse energy can be concentrated in a finite set of narrowband tones. These spectral lines can be readily processed by both wideband and narrowband receivers. (Note: This is precisely the problem noted by Dr. Per Enge, Stanford University, in his demonstration of a low power UWB source which serious degraded GPS reception at distances exceeding 100 meters.)
>
> (Peak envelope power) x (pulse duration) = Energy/bit, which is a direct measurement of the potential communications performance of a pulse-type (UWB) system. Thus, PEP together with antenna gain set the effective communications (and interference) range for a UWB source. Note that for a UWB pulse waveform, pulse duration or pulsewidth (PW) is directly proportional to the reciprocal of the instantaneous bandwidth (BW) – i.e.,
>
> $$PW \propto 1/BW.$$

Claim 2:

"Pulse desensitization is not applied to unintentional radiators. The short pulses of UWB devices look much like the short pulses produced by computer motherboards due to the fast switching."

Response to Claim 2:

Unfortunately, UWB devices are *designed* to emit, incorporating antennas to produce an electromagnetic far field effect. Fast rise time, step excitation of a circuit board trace designed to support high-speed digital signal processing functions, on the other hand, produces significantly smaller (if not negligible) far field effects.

Claim 3:

"Time Domain has shown that the short pulses associated with UWB emissions do not cause the front ends of receivers to become nonlinear, which would be the primary reason for trying to find the peak envelope power by pulse desensitization."

Response to Claim 3:

Unfortunately, while it is true that low power UWB emissions most likely will not cause a receiver front end to become nonlinear, this is not the point. Receiver front end electronics are *inherently* nonlinear by their very nature.

For example, each device following the antenna can be characterized by its 1dB compression and 3rd order intercept points. With multiple, simultaneous tones (or wideband noise-like spectra) introduced in-band into a receiver front end from a UWB source, a multiplicity of intermodulation products will result. These, in turn, can cause considerable degradation of sensitive RF systems. Note, that these effects are directly proportional to the peak envelope power of the UWB source.

Claim 4:

"Utilizing a pulse desensitization factor for UWB systems would needlessly penalize the available emissions by more than 20 dB. Cutting the allowed power by that factor would render UWB products no longer commercially viable."

Response to Claim 4:

As noted above, PEP x (pulse duration) = Energy/bit, which completely determines the performance of a UWB system given a specific modulation strategy (i.e., receiver operating characteristics). Thus, PEP is perhaps *the most important* parameter of a UWB system.

Given a maximum PEP for reliable performance, a decrease in duty cycle results in a corresponding decrease in average power. Decreased average power directly results in decreased interference.

Thus, it is perhaps more appropriate to consider UWB systems as a class (or perhaps *super*class) of spread spectrum (SS) emissions having non-constant envelope characteristics. Unlike direct sequence and frequency hopping spread spectrum, UWB typically exhibits extremely low duty cycles. This, of course, comes with a penalty in range performance. As with Spread Spectrum, however, peak envelope power sets performance.

With both frequency hopped and direct sequence spread spectrum waveforms, peak power is equal to average power. Thus, *with a peak power constraint*, UWB waveforms can provide lower average power densities by allowing the peak-to-average ratio to increase.

In summary,

UWB communications waveforms should be considered *intentional* radiation;

FCC should consider establishing a *peak power limit* for UWB emissions, but allow for arbitrary peak-to-average ratios (the higher the peak-to-average ratio, subject to a peak power limitation, the lower the average power emitted and the lower any interference potential); and,

Pulse desensitization factors must be maintained, given conventional spectrum measurement techniques for establishing average power, so as to limit peak pulse power output.